RESEARCHBRIEF

THE INSTITUTE FOR SYSTEMS RESEARCH

The Microchip Optera Project

Photo: Dr. Elisabeth Kalko

As they seek to capture aerial targets, bats can sort echoes from their own vocalizations from the signals and echoes produced by other bats. This project aims to produce a neuromorphic VLSI-based system with similar abilities.

The potential

Bats use sonar to fly through their environment and catch insects in complete darkness. Studying their behavior and neurophysiology may help in building miniature autonomous air vehicles with sonar sensors.

The long-term goal of this project is to build a tiny, low-power, neuromorphic VLSI-based model of an FM bat echolocation system that can be demonstrated in an aerial target capture task using a flying vehicle. This system will work in real time and at low power.

Echolocating bats

Bats use ultrasonic vocalization signals as their sonar pulse and construct some type of 3-D representation of the environment with the returning echoes. A bat's sophisticated sonar processing system can clearly support a sufficiently detailed spatial percept which they use to guide complex maneuvers, such as insect capture on the wing. Exactly to what degree they perceive a spatial "image" is unknown.

Bats use binaural differences in echo arrival time, intensity and spectrum for horizontal localization. The big brown bat, Eptesicus fuscus, has been shown to have a horizontal localization accuracy of about 1 degree. On the other hand, they use only spectral cues for vertical localization. The pinnae, the tragus, and the head collectively form a complex direction-dependent acoustic filter that influences the spectral profile of the returning echo and plays a critical role in the bat's ability to localize targets in the vertical plane. A bat's vertical discrimination threshold is about three degrees.

With sound traveling at speed of about 34cm (out and back means 17cm target range) for every millisecond of delay time, bats show astonishing accuracy along the range (near/far) axis. Given that their internal neural representation of sensory signals are voltage spikes of about millisecond duration, bats are able to aggregate signals from many neurons to easily distinguish targets that differ by ranges of 1 cm. Many experiments, while controversial, show significantly better resolution.

Echolocating bats can organize acoustic information from multiple targets, arriving from different directions and at different delays. The spatial information comes when the sound, reaching the ears, undergoes transformation in the bat's brain. A class of neurons in the brain show echo-delay tuning, a response property believed to play a role in target ranging. These neurons respond selectively to pulse-echo pairs, separated by particular delays. Other cells are sensitive to the relative intensity of sounds in the two ears and are selective for targets from certain ranges of angles.

What is neuromorphic VLSI?

Neuromorphic VLSI merges current knowledge about the morphology of neurons and neural circuits with parallel

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VLSI computational architectures. Brains primarily use a combination of massively-parallel, nonlinear, analog computations and asynchronous digital communication. For example, a silicon retina is a camera-like chip with photoreceptor pixels that perform image processing in the space surrounding each pixel. This is analogous to what occurs in mammalian retinas.

Developing sonar capabilities (bearing and range)

ISR researchers are studying how the physical shape of a bat's head, its flight behavior, its choice of sonar pulse and its repetition rate contribute to the incredible sensory performance it achieves. Engineering efforts to replicate some of these tasks do not come anywhere near the performance in weight, speed and power consumption of a common bat.

The separate extraction of sensory attributes is a common theme in neural computation and the neuromorphic bat system is a good example of this processing approach.

To mimic the neurons that detect target range, the researchers use analog circuit models of the bat's delay-tuned cells to design a neuromorphic chip that implements range detection based on echo delay. This model uses a cellular rebound mechanism to correlate the time of flight to an internal time constant. Place coding is achieved with arrays of units tuned to different delay times.

To mimic the neurons that detect target bearing (azimuth), the researchers use an array of cells active for targets beyond a certain threshold angle. As with the delay-tuned cells, angle is extracted from the population response of cells with different threshold angles.

Consistent with the low-power nature of these computations, the circuits operate with a power consumption on the order of milliwatts.

Status

The researchers currently are developing low-power ultrasonic cochleae for use in broadband echo analysis, to extract target elevation, and to pursue more complex integration of sensory cues for guiding the flight of their test vehicle.

Research team

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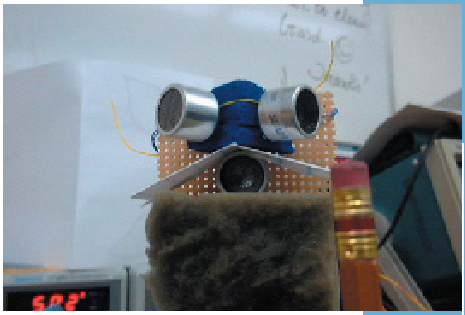

Narrowband test system (40 kHz)

Wideband system (10 kHz to 100 kHz)